ON THE PLANKTONIC AND EPIPHYTIC DESMIDS (DESMIDIALES, CHLOROPHYTA) OF SOUTHERN WISCONSIN HARD WATERS

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Our knowledge of the desmid flora of southern Wisconsin hard waters (here defined as waters with > 30 mg per l Ca^{+2}, following the scheme of Sawyer & McCarthy, 1967) is limited. Smith (1924) examined the desmid plankton of selected lakes throughout the state but gave no indication of the chemical conditions at his study sites, nor did he examine the aufwuchs component. Sloey and Blum (1972) investigated the algal flora of hard water Lake Winnebago and reported the presence of two species of desmids in the aufwuchs and one in the plankton, but accounts of other investigations (e.g., Marsh, 1903) are restricted to generic determinations.

Desmid generic diversity is decidedly lower in hard waters than in soft waters (Hutchinson, 1967; Gough & Woelkerling, 1976) and the same appears to be true for desmid species (Smith, 1924; West & West, 1896). Smith (1920, p. 8), for example, states that fewer than one or two species were found in the plankton of the hard water lakes of southern Wisconsin whereas soft water bogs may harbor hundreds of species.

The factors responsible for the low diversity in hard water environments are not clear but may involve pH levels, calcium concentrations, conductivity levels or an interaction of these parameters (see Woelkerling & Gough, 1976, for a review of the literature on this subject). With few exceptions, the desmids occurring in hard waters are species of *Closterium, Cosmarium* or *Staurastrum* (Gough & Woelkerling, 1976; Smith, 1924; and others) and of these taxa, most are considered to be unusually tolerant forms which grow in soft waters as well; only a few have been suspected of preferring a hard water environment (Hutchinson, 1967). However, little attempt has been made to determine the chemical tolerance of individual taxa. Moreover, the chaotic state of desmid systematics

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makes it difficult to make comparisons between studies, especially when few authors cite the taxonomic sources used in the identification of their taxa.

Two major hard water lentic environments exist in Wisconsin: lakes (particularly those in the southern part of the state) and calcareous spring ponds. The latter type consists of impoundments fed by artesian sources from aquifers within or running through limestone bedrock or glacial till; these are especially prevalent in southeastern Wisconsin. The lakes and spring ponds differ in the ranges and mean levels of certain chemical parameters (Table 2), particularly conductivity, pH, CO_2, some nitrogen compounds, calcium and alkalinity.

To further our understanding of desmids in hard water environments, this report presents a floristic account of the species found in 20 hard water lakes and six calcareous spring ponds in southern Wisconsin. Comments on diversity, the frequency of occurrence of taxa in the plankton and aufwuchs, morphological variation within populations and distribution in relation to water chemistry are also included.

Table 1. **Conspectus of Desmid Species in Southern Wisconsin Hard Water Lakes and Spring Ponds.**

1.	Plants without a median constriction	2.
2.	Distance between apices less than 100μ	*Closterium venus.*
2.	Distance between apices greater than 200μ	*Closterium moniliferum.*
1.	Plants with a median constriction	3.
3.	Semicells with an apical incision	*Euastrum pinnatum.*
3.	Semicells without an apical incision	4.
4.	Semicells with divergent processes	5.
5.	Semicell base inflated	*Staurastrum longiradiatum.*
5.	Semicell base tapered to the isthmus	*Staurastrum manfeldtii.*
4.	Semicells without processes	6.
6.	Plants greater than 6 times longer than broad	*Pleurotaenium maximum.*
6.	Plants less than 2 times longer than broad	7.
7.	Semicells with lateral incisions	*Micrasterias truncata.*
7.	Semicells without lateral incisions	8.
8.	Semicells granulate	9.
9.	Semicell apex flattened	*Cosmarium botrytis.*
9.	Semicell apex rounded	*Cosmarium punctulatum.*
8.	Semicells pitted	*Cosmarium granatum.*

Geographic and biological host data for the study sites are listed in Table 2 and a summary of the water chemistry is found in Table 3. Scanning electron micrographs referenced in the checklist are found in Figures 1–15.

MATERIALS AND METHODS

Ten to 25 l of water were strained through a No. 25 silk mesh plankton net and the plankton concentrate was preserved with FAA (10 : 7 : 2 : 1 :: 95% EtOH : distilled H_2O : formalin : acetic acid). Portions of macrophytes were collected and subjected to agitation and hydrolysis for removal and examination of the aufwuchs (see Gough & Woelkerling, 1976, for procedural details). Several glass slides were made of each plankton and aufwuchs concentrate using a glycerin jelly-fast green mounting medium and Hoyer's solution. The former provided stained cytoplasm which allowed recognition of characters such as pyrenoid arrangement and chloroplast structure whereas the latter provided cleared cells for examination of cell wall sculpturing. Voucher material has been deposited in my personal herbarium.

Living samples were taken twice at most sites during the period of June 1-August 30, 1973. Collections were transported on ice to the lab where clonal isolates were established in modified Waris medium (Waris, 1953; 90% medium + 10% soil water extract) using the capillary tube isolation technique (Hoshaw, et al., 1973). Established cultures which were representative of field populations were then used for scanning electron microscopy (SEM) and SEM micrographs (Figures 1–15) were produced for those taxa in which wall ornamentation is of primary taxonomic value. The advantages of SEM and the procedures used and the difficulties encountered in the preparation of desmid samples for SEM are outlined elsewhere (Gough, Garvin, & Woelkerling, 1976).

Tests for CO_2 and pH were done in the field with a HACH Chemical Company Water Analysis Field Kit, Model DR-EL, and calcium was determined in the lab by the EDTA titrimetric method (APHA, 1971). Other parameters were analyzed by the Wisconsin Department of Natural Resources, Delafield Laboratory (see Woelkerling, 1976, for details of the methods used).

Table 2. **Study sites: Geographic and Biological Host Data.**

COUNTY	SITE	LOCATION T	R	S	AREA (ha)	AUFWUCHS HOSTS*
Dane	Bruner's Pond	6N	7E	11	1	C,M,PP
	Fish L.	9N	7E	3	102.06	C,M,N,U
	L. Waubesa	6N	10E		855.76	M
	L. Wingra	7N	9E	27	139.72	C,M
Green Lake	Green L.	15N	12E		2966.62	M,N
Iowa	Cox Hollow L.	6N	4E	10,11	38.88	A,C
	Twin Valley L.	6N	3E	1	59.54	C,PC
Jefferson	Ripley L.	6N	13E	7	175.37	M,N,PC,U
	Rock L.	7N	13E		555.26	C,M
Racine	Tichigan L.	4N	19E		360.86	C
Walworth	L. Beulah	4N	18E		338.99	A,M,PP,U
	L. Geneva	1,2N	16,17E		2131.11	C,M
	Whitewater L.	3,4N	15E		259.20	PP
Waukesha	Fowler L.	8N	17E	33	31.59	A,Ch,M,PP
	Golden L.	7N	17E	30,31	101.25	M,Na,PP
	L. Nagawicka	7N	18E	8,17	371.38	A,M
	Okauchee L.	8N	17E	18	480.74	M,PP
	Pewaukee L.	7N	18,19E		1009.66	Ca,M
	School Section L.	6N	17E	16,17	50.62	M,PC
	Silver L.	7N	17E	9,16	89.91	Ch,S
	Spring Pond "A"	5N	17E	3	0.01	A,H
	Spring Pond "B"	6N	18E	21	0.01	A,Ch
	Spring Pond "C"	6N	18E	21	0.01	Ch,RL
	Spring Pond "D"	6N	18E	21	0.005	Ch,RL
	Spring Pond "E"	6N	18E	21	0.002	Ch
	Spring Pond "F"	6N	18E	21	0.002	Ch

*A = *Anacharis*, C = *Ceratophyllum*, Ca = *Carex*, Ch = *Chara*, H = *Hippuris*, M = *Myriophyllum*, N = *Nuphar* (petioles), Na = *Najas*, PC = *Potamogeton crispus*, PP = *Potamogeton pectinatus*, RL = *Ranunculus longirostris*, S = *Scirpus*, and U= *Utricularia*.

RESULTS AND DISCUSSION

Taxa Present

The following is a checklist of the ten species of desmids found at the study sites. Populations of each taxon conformed to all descriptions and illustrations cited, and a conspectus of the taxa is found in Table 1. Percentage figures are based on presence/absence data from all sites (lakes and spring ponds).

Closterium Nitzsch ex Ralfs

Closterium moniliferum (Bory) Ehrenberg ex Ralfs **1848:** 166. *pl. 28, fig 3.* Irénée-Marie **1939:** 66. *pl. 5, figs. 1, 2.* Krieger **1937:** 289. *pl. 18, figs. 6, 7.* Sloey and Blum **1972:** 139. Smith **1924:** 9. *pl. 52, fig. 10.*

Plants of this species were common in the aufwuchs of the hard water lakes, occurring at 19% of all study sites, but none were found in the plankton.

A few cells (ca. 2%) in about half of the populations displayed a slightly scattered pyrenoid arrangement rather than the typical single row positioning.

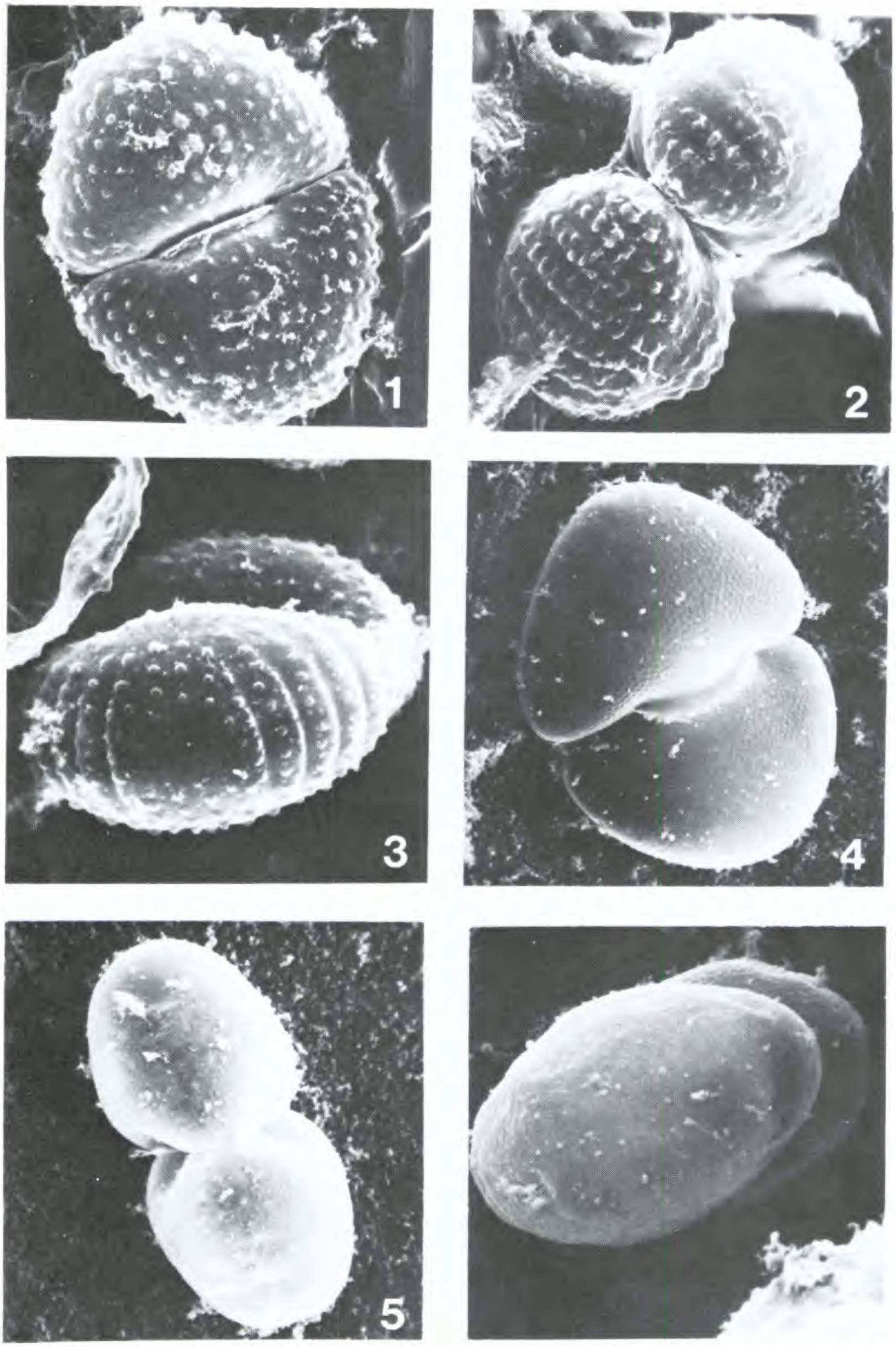
Closterium venus Kützing ex Ralfs **1848:** 220. *pl. 35, fig. 12.* Irénée-Marie **1939:** 70. *pl. 4, figs. 14–16. Krieger* **1937:** 272. *pl. 16, figs. 1–5.* Smith **1924:** 9. *pl. 52, fig. 9.*

Like *Closterium moniliferum,* no cells were found in the spring ponds or in the plankton of the lakes. However, the taxon was commonly encountered in the lake aufwuchs (found at 27% of all sites) where it often occurred on *Myriophyllum* and *Ceratophyllum.*

Cosmarium Corda ex Ralfs 1848

Cosmarium botrytis (Bory) Meneghini ex Ralfs **1848:** 99. *pl. 16, fig. 1.* Hirano **1957:** 182. *pl. 27, fig. 13.* Irénée-Marie **1939:** 210. *pl. 26, fig. 4.* Smith **1924:** 33. *pl. 57, fig. 22.* Text figures 1–3.

Although these plants were seldom confused with other taxa, the prominence of the basal cluster of granules varied within most populations and a few cells with larger granules resembled *Cosmarium sportella* Brébisson ex Ralfs 1848, as described by Irénée-Marie, 1939, p. 200, *pl. 24, fig. 9.*



Figures 1–6, **Cosmarium.** 1, *C. botrytis* (Bory) Meneghini ex Ralfs (1200×); 2, *C. botrytis* (Bory) Meneghini ex Ralfs (1600×); 3, *C. botrytis* (Bory) Meneghini ex Ralfs (2000×); 4, *C. granatum* Brébisson ex Ralfs (1900×); 5, *C. granatum* Brébisson ex Ralfs (2100×); 6, *C. granatum* Brébisson ex Ralfs (3000×).

Cells of this species were found in the aufwuchs of 54% of the sites (in lakes only) and in one lake plankton sample, making it the most commonly found *Cosmarium* taxon.

Cosmarium granatum Brébisson ex Ralfs **1848:** 96. *pl. 32, fig. 6.* Hirano **1957:** 129. *pl. 20, fig. 25.* Irénée-Marie **1939:** 167. *pl. 23, fig. 13.* Smith **1924:** 31. *pl. 57, fig. 18.* Text figures 4–6.

The distinction between this taxon and *Cosmarium subtumidum* Nordstedt as described by Irénée-Marie, 1939, p. 167. *pl. 27, fig. 17*, is tenuous since it is based on a minor variation in cell shape which is not readily evident in the illustrations.

This species never occurred in the spring ponds or in the lake plankton but was found in the aufwuchs at 23% of the sites where it often displayed high population densities.

Cosmarium punctulatum Brébisson **1856:** 129. *pl. 1, fig. 16.* Hirano **1957:** 183. *pl. 27, fig. 15.* Irénée-Marie **1939:** 204. *pl. 31, fig. 1.* Text figures 7–9.

The semicircular semicells and prominence and arrangement of granules in this taxon were stable characters in the populations examined.

No cells occurred in the spring ponds but one lake harbored the species in its plankton and 42% of all sites contained it in their aufwuchs.

Euastrum Ehrenberg ex Ralfs 1848

Euastrum pinnatum Ralfs **1848:** 81. *pl. 13, fig. 1.* Hirano **1959:** 255. *pl. 32, fig. 15.* Irénée-Marie **1939:** 120. *pl. 13, fig. 3.* Krieger **1937:** 522. *pl. 68, figs. 5–7.* Smith **1924:** 24. *pl. 56, fig. 5.* Text figure 10.

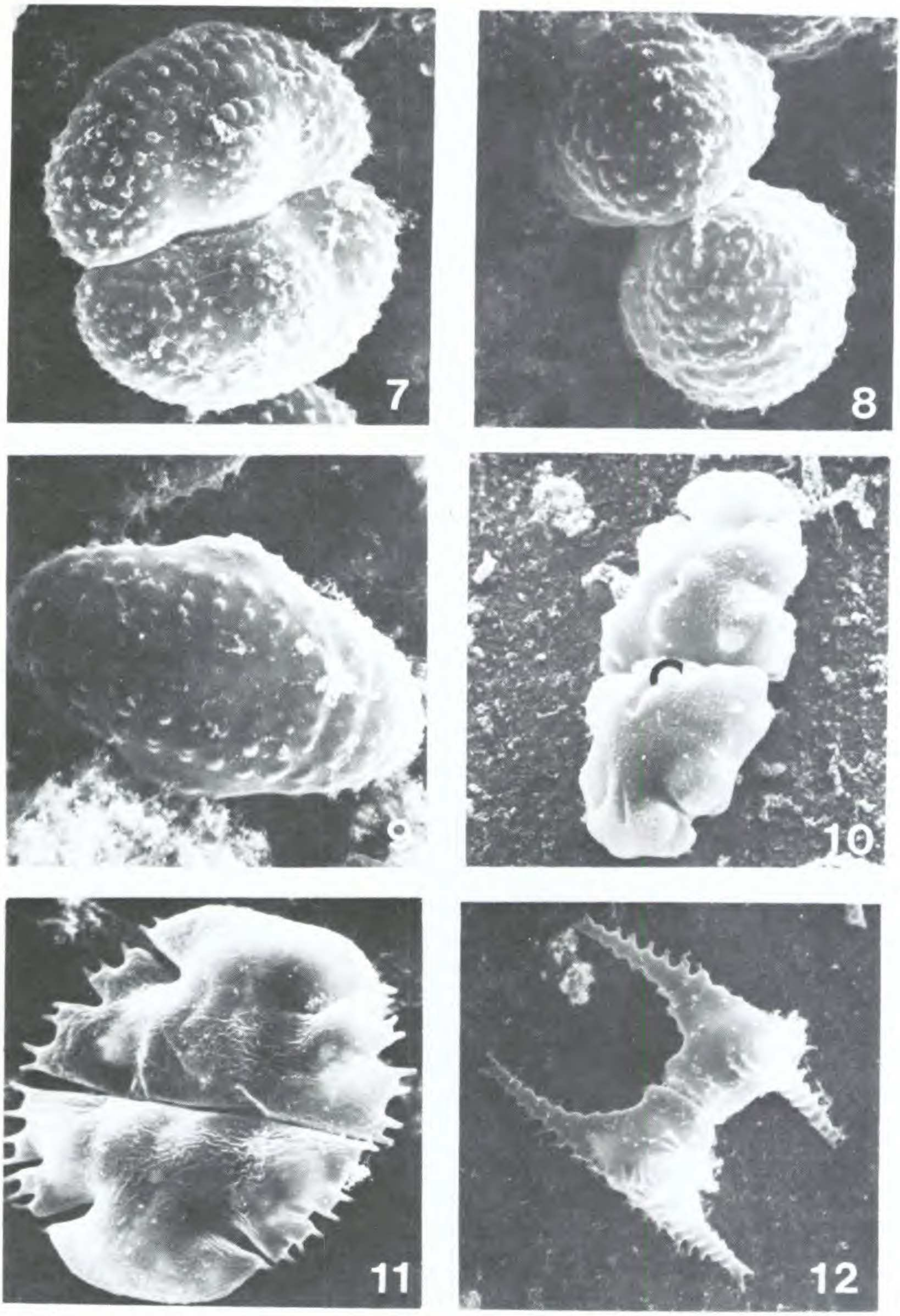
This taxon was found in the aufwuchs of only one lake.

Micrasterias Agardh ex Ralfs 1848

Micrasterias truncata (Corda) Brébisson ex Ralfs **1848:** 75. *pl. 8, fig. 4; pl. 10, fig. 5.* Hirano **1959:** 272. *pl. 36, figs. 4, 5, 17.* Irénée-Marie **1939:** 221. *pl. 33, figs. 2–7; pl. 34, fig. 2.* Krieger **1937:** 25. *pl. 102, figs. 1–4.* Smith **1924:** 43. *pl. 60, figs. 1, 2.* Text figure 11.

This taxon was found in the aufwuchs of only one lake.

Pleurotaenium Nägeli 1849



Figures 7–12, **Cosmarium, Euastrum, Micrasterias, and Staurastrum.** 7, *C. punctulatum* Brébisson (2600×); 8, *C. punctulatum* Brébisson (2200×); 9, *C. punctulatum* Brébisson (2700×); 10, *E. pinnatum* Ralfs (600×); 11, *M. truncata* (Corda) Brébisson (1000×); 12, *S. longiradiatum* W. & G. S. West (1000×).

Pleurotaenium maximum (Reinsch) Lundell **1871:** 89. *pl. 4, fig. 2.* Irénée-Marie **1939:** 94. *pl. 10, figs. 3, 4.*

Although only found in the aufwuchs of one lake, *Pleurotaenium maximum* occurred there in abundance.

Staurastrum Meyer ex Ralfs 1848

Staurastrum longiradiatum W. & G. S. West **1896:** 267. *pl. 17, fig. 23.* Hirano **1959:** 363. *pl. 46, figs. 1, 2.* Smith **1924:** 90. *pl. 74, figs. 5–11.* Text figures 12, 13.

The prominence of the basal inflation on each semicell was variable but consistently distinctive.

Found commonly in the lake plankton (encountered at 27% of all sites), the species only occurred in the aufwuchs of one lake, possibly adventitiously.

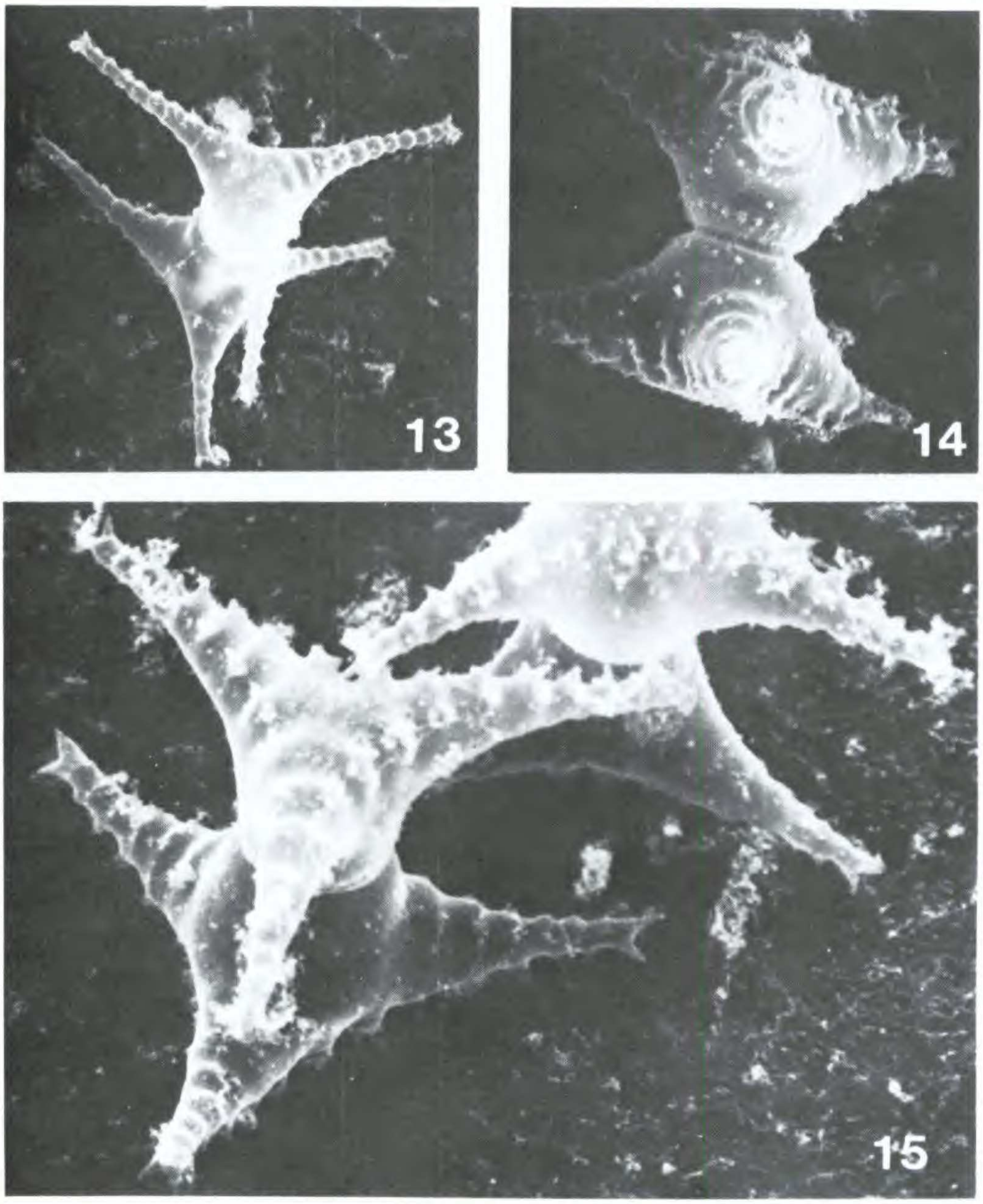
Staurastrum manfeldtii Delponte **1873:** 64. *pl. 13, figs. 6–19.* Hirano **1959:** 368. *pl. 48, fig. 1.* Irénée-Marie **1939:** 309. *pl. 48, fig. 4.* Text figures 14, 15.

Like *Staurastrum longiradiatum,* this species was only found in the aufwuchs of one lake. However, it occurred in 15% of the plankton samples, including one spring pond (where it represented the only desmid taxon recovered from such environments).

Ecological Observations.

No *Closterium, Euastrum, Micrasterias* or *Pleurotaenium* species were found in the plankton, and the latter three were only found at single localities. Likewise, *Cosmarium* was rarely found in plankton but was common in the aufwuchs, whereas the opposite was true of *Staurastrum.* The only taxon occurring in the spring ponds (one locality) was *Staurastrum manfeldtii.*

Zero to three desmid species occurred in the plankton of the lakes (consistent with Smith's (1920) observations of low diversity in hard waters) with a mean of 0.7 per site; 0–1 planktonic taxa occurred at the calcareous spring ponds where the mean was only 0.2 per site. The aufwuchs of the lakes harbored greater species numbers (range 0–8, mean 3.1 per site) whereas no desmid species were encountered in the spring pond aufwuchs samples. These data parallel results found at the generic level (Woelkerling & Gough, 1976) where



Figures 13–15, **Staurastrum.** 13, *S. longiradiatum* W. & G. S. West (1100×); 14, *S. manfeldtii* Delponte (1300×); 15, *S. manfeldtii* Delponte (1500×).

diversity was generally greatest in softer water and in the aufwuchs of any given site. Moreover, *Utricularia* was found to harbor more desmid species than any other macrophyte at each site, a result also consistent with findings at the generic level (Woelkerling & Gough, 1976). However, no obvious specificity of a taxon for a particular macrophyte was noted.

Table 4 lists the ranges of chemical parameters under which the 10 desmid species were found. Such a listing does not indicate the tolerance of the taxa to the chemical parameters as only a select group of environments (which do not cover the full potential water chemistry range) were analyzed. However, the table does indicate that most taxa, particularly the *Cosmarium* species, are capable of occurring under widely different chemical regimes. *Cosmarium botrytis*, for example, which occurred in the aufwuchs of 54% of the sites, was found at the extremes of virtually all the chemical parameters. The three taxa occurring at only one locality (*Euastrum pinnatum, Micrasterias truncata* and *Pleurotaenium maximum*) were found at rather high levels of conductivity, pH and calcium. Since most species within these genera seem confined to soft waters, it is curious that these taxa, if they represent eurytopic species within the genera, were not found at more localities.

Apart from the observation that the number of desmid species was lower in the spring ponds than in the lakes sampled, no obvious correlations were found between water chemistry and species diversity. Factors potentially responsible for the lower diversity in spring ponds are discussed in Woelkerling and Gough (1976) and may involve the frequent occurrence of higher levels of calcium, conductivity and alkalinity in the ponds or a possible competitive advantage of other algae at the lower temperatures. The low diversity is in apparent disagreement with Moss's (1973a) findings that high levels of free CO_2 are conducive to desmid development.

Determination of the occurrence of desmid taxa in relation to the full range of water chemistry requires a look at several additional habitats, including, in particular, acid bogs and soft water lakes. Unfortunately such studies are hampered by the chaotic state of the systematics. If several distinct taxa can be recognized, however, their distribution in nature and behavior in culture under different chemical regimes might lead to a better understanding of desmid ecology. Although Gough (1977), Moss (1972, 1973, a,b,c), Tassigny (1971) and others have reported on such studies, many taxa under several different culture conditions will need to be evaluated before generalizations can be attempted.

Tyler (1973) has remarked that the state of confusion in desmid systematics has virtually necessitated the determination of species by comparative iconography. Problems with the use of existing

Table 3. **Summary of water chemistry conditions. All values expressed in mg/l except for conductivity (μmho/cm) and pH (units).**

	SPRING PONDS		HARD WATER LAKES	
PARAMETER	RANGE	MEAN	RANGE	MEAN
Conductivity	520–619	584	228–495	396
pH	7.3–7.5	7.4	8.3–9.8	8.7
CO_2	24–32	29	0–15	1
O_2	4.0–9.0	7.7	—	—
PO_4-P	.014–.030	.020	.009–.112	.039
Total P	.03–.06	.042	.01–.17	.08
NO_2-N	.002–.021	.010	.000–.032	.009
NO_3-N	2.35–2.94	2.62	.04–1.13	.19
NH_3-N	.05–.23	.15	.03–.51	.10
Org. N	.34–.66	.57	.62–2.10	1.13
Total N	3.07–3.63	3.34	.76–2.73	1.40
Total Alkalinity	247–290	271	110–324	192
Ca^{++}	50–74	66	30–74	45
Mg^{++}	25–43	36	—	—
Cl^-	21–32	26	8–61	23
$SO_4^=$	27–32	30	3–36	22

taxonomic works, particularly keys to the species of *Cosmarium* and *Staurastrum,* to which hundreds of taxa are assigned, are several: (1) the use of cryptic morphological distinctions such as elliptical vs. semielliptical (e.g., Hirano, 1959), (2) the apparent tendency to recognize every polymorphic variant as a taxon, and (3) the frequent lack of correlation between the representations of the same taxa by different authors (e.g., cf. *Staurastrum gracile* Ralfs 1858 in Smith (1924, p. 88. *pl. 73, figs. 16–18*) and Irénée-Marie (1939, p. 313. *pl. 48, fig. 13*)). Thus, until extensive monographic work, which incorporates an evaluation of polymorphism in field and culture populations, reduces the confusion attending desmid systematics, it seems imperative that citations to specific taxonomic works accompany every taxon reported in the literature. Moreover, the prevalent use of desmids in various indicator schemes (e.g., Fjerdingstad, 1965; Nygaard, 1949; Palmer, 1969; Thunmark, 1945) which require species determinations suggests the need for careful taxonomic work in their application and possible revision of the schemes as the taxonomy is revised.

Table 4. **Range of chemical conditions under which desmid species occurred.***

TAXON	CONDUCTIVITY	pH	CO_2	PO_4-P	TOTAL P	NO_2-N	NO_3-N
Closterium moniliferum	377–495	8.3–9.1	0–6	.017–.112	.05–.17	.003–.026	<.04–.59
C. venus	361–474	8.3–9.3	0–3	.015–.100	.02–.12	.000–.020	<.04–1.13
Cosmarium botrytis	228–490	8.3–9.8	0–15	.009–.112	.01–.17	.000–.032	<.04–1.13
C. granatum	228–490	8.3–8.7	0–15	.015–.051	.02–.07	.000–.032	.06–.39
C. punctulatum	228–490	8.3–8.8	0–15	.014–.061	.01–.12	.000–.032	<.04–.39
C. subtumidum	228–490	8.3–9.8	0–15	.015–.064	.03–.07	.000–.032	.06–1.13
*Euastrum pinnatum**	441	8.5	0	.037	.03	.000	.08
*Micrasterias truncata**	461	8.3	0	.017	.05	.020	.11
*Pleurotaenium maximum**	375	8.8	0	.023	.08	.003	<.04
Staurastrum longiradiatum	228–474	8.5–9.3	0–3	.009–.112	.02–.17	.000–.023	<.04–.12
S. manfeldtii	323–520	7.4–8.8	0–28	.014–.064	.05–.08	.002–.020	<.04–2.72

Table 4 continued

TAXON	NH_3-N	ORG. N	TOTAL N	TOTAL ALKALINITY	Ca^{++}	Cl^-	$SO_4^=$
Closterium moniliferum	.04–.51	1.08–1.88	1.28–2.73	150–254	41–74	14–61	23–32
C. venus	<.03–.12	.64–1.48	.76–2.11	150–240	34–58	13–61	3–28
Cosmarium botrytis	<.03–.38	.62–2.10	.76–2.16	110–324	30–63	10–61	3–36
C. granatum	<.03–.12	.64–.99	.76–1.53	110–324	34–63	13–27	3–36
C. punctulatum	<.03–.51	.64–1.88	.76–2.73	110–324	34–74	13–61	3–36
C. subtumidum	<.03–.12	.84–2.10	.98–2.16	110–324	33–63	10–27	3–14
*Euastrum pinnatum**	<.03	.72	.80	190	54	16	36
*Micrasterias truncata**	.07	1.08	1.28	150	41	61	23
*Pleurotaenium maximum**	.04	1.48	1.52	188	45	18	27
Staurastrum longiradiatum	<.03–.16	.62–1.67	.85–1.91	110–204	30–58	13–49	3–28
S. manfeldtii	.03–.38	.34–1.48	1.00–3.29	171–247	35–50	8–25	8–32

*Denotes taxon occurred at a single locality.

SUMMARY

The poorly known desmid flora of southern Wisconsin hard waters was investigated in 20 lakes and 6 calcareous spring ponds. Ten species (2 *Closterium*, 3 *Cosmarium*, 1 *Euastrum*, 1 *Micrasterias*, 1 *Pleurotaenium* and 2 *Staurastrum* taxa) were found. A few species displayed some polymorphism but most were clearly distinguishable entities. *Closterium*, *Euastrum*, *Micrasterias* and *Pleurotaenium* were confined to the aufwuchs, and *Cosmarium* was seldom found elsewhere, whereas *Staurastrum* usually only occurred in the plankton. *Cosmarium botrytis* was the most common taxon encountered, whereas species of *Euastrum*, *Pleurotaenium* and *Micrasterias* were only recorded at single localities. Species diversity was greatest in the aufwuchs at all sites and was lower in the spring ponds than in the lakes. Many of the taxa (especially *Cosmarium* species) occurred over a wide range of chemical conditions but no correlations were found between water chemistry and species diversity.

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